Seafloor Geomorphology, Gas & Fluid, and Slope Failure on the Southern Cascadia Continental Margin

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LONG TERM GOALS

Our long term goal is to understand the interaction of fluid flow, gas migration and tectonics in the creation and modification of shelf and slope geomorphology and seafloor acoustic character. In addition, we are examining the interaction of tectonics, sediment accumulation and erosion in creating and modifying the morphology, stratal architecture and preservation potential of continental margins.

OBJECTIVES

We combine seafloor data, geochemical analyses of cores and precipitates, and subsurface imaging to examine how hydrogeology, natural gas, eustasy, oceanographic forcing and tectonics interact and influence submarine geomorphology. Our objective is to determine the causes of anomalous seafloor bathymetry and reflectivity, and to relate reflectivity to gas migration, subsurface structure, and consolidation state.

APPROACH

The data sets we use are derived from a broad range of platforms. For seafloor data, we interpret EM-1000 multibeam bathymetry and backscatter as well as towed side scan data. Additional data include a Hydrosweep multibeam survey collected adjacent to the main STRATAFORM area. For the subsurface, we are analyzing a nested suite of seismic data, including commercial multichannel seismic (MCS) reflection data, provided by Amoco Corp; high resolution MCS data (Craig Fulthorpe, UTIG and Greg Mountain, LDEO); and even higher resolution Huntec (Mike Field, USGS) and EdgeTech CHIRP data (Neal Driscoll, WHOI). These nested subsurface techniques are then combined with seafloor bathymetry and reflectivity data to determine the relationship between structure, gas, bathymetry and reflectivity. To groundtruth our hypotheses we utilize surface coring techniques to obtain samples for geochemical analysis, as well as ROV observations and samples collected in 1997. We integrate these observations and analyses with the seafloor and subsurface data to analyze active vs. dormant processes, and to evaluate the role of fluid and/or gas migration in creating or modifying seafloor structures.

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WORK COMPLETED

* A re-examination of industry and hi-resolution multi-channel seismic data demonstrates that the oblique tectonic fabric of the northern California accretionary complex imposes first order controls on the distribution and fate of shelf and slope sediments. On the slope, anticlinal highs with seafloor expression route sediments into the neighborhing synclinal lows. This geometry leads to shelf-edge deltas constrained between the structural highs. The “Humboldt Slide” occupies the delta front and pro-delta portion of the shelf-edge delta.

* The “Ridge and Swale Zone” of long wavelength bathymetric highs and lows north of the Little Salmon anticline is characterized by unusual slope bedforms slightly oblique to isobaths. We interpret these to be related to along-slope (south to north) sediment delivery constrained by gaps in the en echelon Little Salmon anticline. Sediment delivery and deposition may have been more active during lowstand and early sea level transgresion.

* Analyses of head space gas samples from cores collected during the 1999 field season (in collaboration with T. Lorenson and K. Kvenvolden, USGS). Significant methane anomalies were encountered in a number of cores on both the shelf and slope.

* Slope methane anomalies are widespread, suggesting a relationship to shallow-source (biogenic) gas. Shelf methane anomalies, in contrast, correspond to two different regimes. One regime is associated with tectonic highs that were also imaged as seismically opaque regions on CHIRP sub-bottom data. The other regime is associated with lagoonal (?) deposits preserved below the transgressive unconformity.

* The association of anomalous gas with multibeam backscatter suggests that high resolution multibeam may be used to evaluate the distribution of shallow gas on both the shelf and slope (see Mayer et al.).

* A detailed study of Huntec and hi-resolution MCS data is being carried out to evaluate the origin of anomalous seafloor features on the slope. These include an upper slope region of localized sediment accumulation and intervening erosion (“the Ridge and Swale zone”) and the “Humboldt Slide. We interpret these features to represent upper slope deposition and erosion affected by sea level and tectonics.

RESULTS

Tectonic Controls on Sediment Accumulation and Preservation on Both the Shelf and Slope

The Eel River margin is characterized by a tectonic fabric that is oblique to the coastline and the shelf-slope break. This obliquity has a significant impact on the locus and style of sediment delivery, accumulation, and preservation. The rise and fall of sea level, coupled with the time varying delivery of sediment to the margin, adds to this impact. Today, the Eel and the Mad River to the north occupy subsiding synclines striking NNW across the Gorda/North American convergent plate margin. The present day anticlines and synclines have a subtle, if any, impact on the seafloor morphology of the continental shelf, yet seismic images (industry 2D MCS, hi-res 2D MCS, and CHIRP profiles) on the

shelf indicate that anticlinal highs are characterized by erosion or compressed sections, whereas synclinal lows have dramatically expanded seismic sections.

On the slope, the prominent high related to the Little Salmon anticline divides the study area into sub-basins. During sea-level lowstand the Little Salmon Fault anticline funneled sediment onto the present-day base of the "Humboldt Slide". We suggest that lowstand delivery to the base of the slide led to bedform formation, whereas the "head" of the Humboldt Slide evolved as a lowstand delta (Figure 1). As sea level rose, the en echelon offsets that cut the Little Salmon anticline provided gaps where along slope sediment transport could occur during early transgressions. During later transgression and high stand conditions, nepheloid-dominated flood deposits bypass and erode the upper slope within the "head" of the Humboldt Slide, but continue deposition on bedforms at the base of the slide.

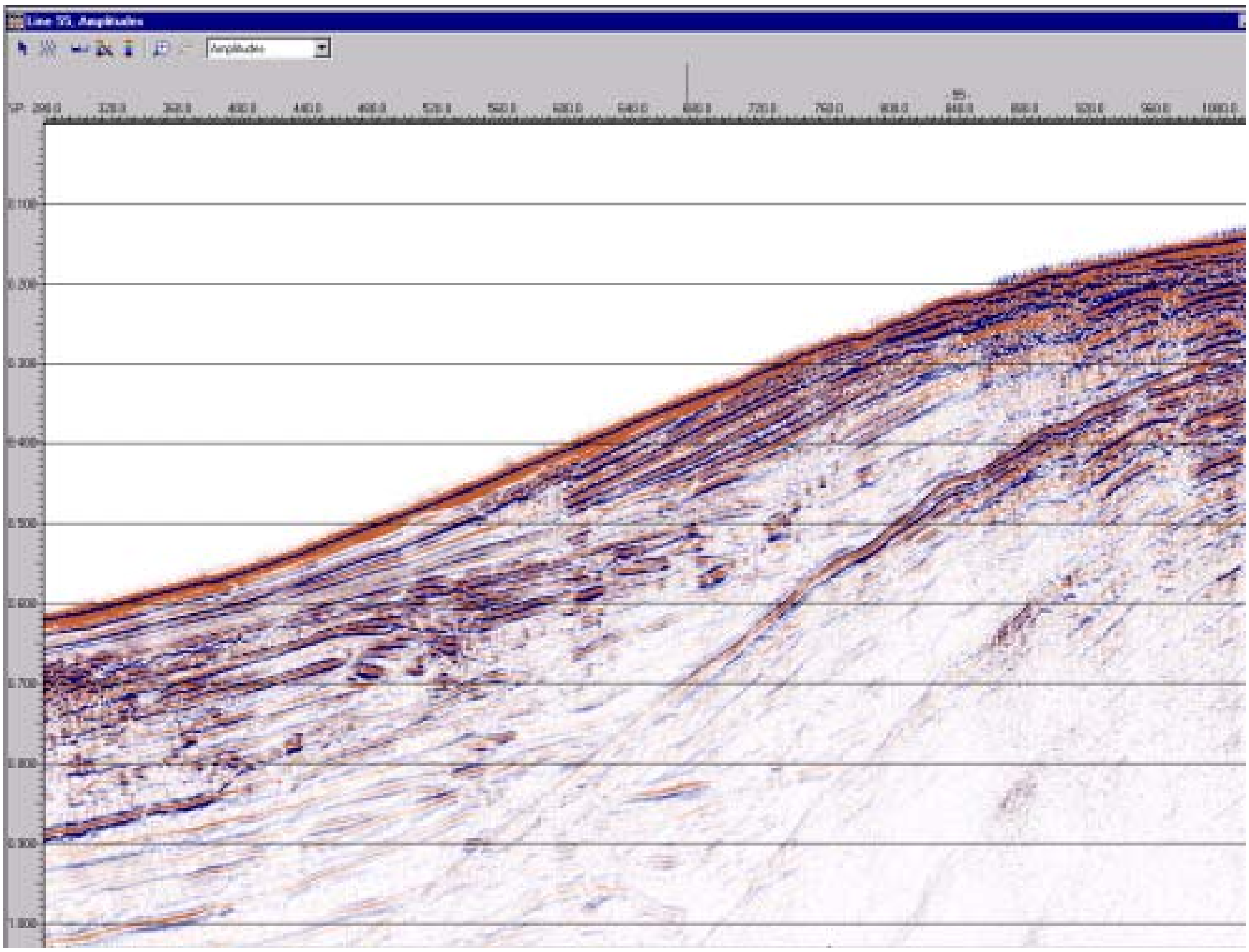

Figure 1: Detail of high-resolution multi-channel seismic line 55, a dip-line through the head of the "Humboldt Slide". Note that the stratal architecture indicates that the 'head' of the slide is underlain by clinoformal deltaic strata.

The broad shelf of the present-day Eel margin minimizes the tectonic control of sediment delivery to the slope, leading to potential depocenters within the Eel Canyon, within the "Humboldt Slide", and on the slope north of the Little Salmon Fault toward the Trinity Canyon.

CHIRP data, however, show that the Little Salmon and related anticlines acted as drainage divides on the shelf as well, although their present-day seafloor signature is muted. The complex interaction of tectonics and sea level strongly affects the delivery, accumulation, and preservation of organic matter as well. We evaluate the distribution of gas on the shelf to demonstrate the competing effects of structurally controlled deep source gas, and stratigraphically (or eustatically) controlled shallow biogenic gas.

Relationship of Shallow Stratigraphy and Tectonics on Gas

Cores obtained from the shelf and slope contain significant concentrations of methane. These cores can be tied to sedimentological features, underlying structural culminations, and sea level. Compositional analysis of cores and ROV samples show that the gas in the Eel River Basin originates from both deep thermogenic and shallow biogenic sources. Previous ROV observations in the context of regional geophysical surveys led to our hypothesizing two different mechanisms for fluid expulsion: continuous along structure vs. episodic (and catastrophic) between structures.

On the slope, we focussed our efforts on two regions where we had inferred high sediment accumulation rates based upon our interpretation of the hi-res MCS and Huntec data: the "Ridge and Swale zone", and the base of the "Humboldt Slide". All of the cores from these sites showed very high gas concentrations, up to 1300 µml/l wet sediment (150,000 ppm). Cores showed parting and bubbles; no cores showed obvious gas hydrates.

On the shelf, the cores were being collected for the sedimentological studies of other ONR researchers (Nittrouer, Summerfield, Wheatcroft, Drake). The core locations were selected to provide broad coverage and even distribution. By analyzing all of the cores for headspace gas we were able to use this grid of samples to comprehensively test for the presence and distribution of shelf gas. Very high gas concentrations were found in 4 cores on the mid- to outer-shelf; all were collected in regions where CHIRP sub-bottom profiles showed evidence of subsurface gas. Anomalous shelf gas samples had up to 580 µmol/l wet sediment (55,000 ppm) gas. The apparent restriction of high shelf gas to a narrow bathymetric range (see Graph) begs the question as to what controls this band of shelf gas (discussed in Yun et al., 1999; see publications). In our on-going gas sampling and analysis program we are evaluating cores collected in July, 2000, again targeted with CHIRP sub-bottom profile data (Driscoll).

An evaluation of multibeam backscatter and gas distribution (see Mayer et al., annual report) suggests a correlation that is a function of water depth. Numerical modeling indicates that interstitial gas in the shallow section can affect backscatter. This suggests that quantitative multibeam backscatter may be useful in evaluation the distribution of shallow gas.

IMPACT/IMPLICATIONS

The recognition of the shelf-edge delta on the Eel River margin, where structures are oblique to isobaths, provides a type locality for understanding deltas that are concave downslope. In contrast to

most deltas, which are convex downslope, the passive drape of slope sediments on the anticlinal highs, and the depocenter created by the subsiding synclinal low, leads to a concave downslope geometry.

Our investigation of seafloor morphology and reflectivity suggests that high resolution multibeam may be of use to the hydrocarbon and cable industries as both an exploration tool and a means of conducting cost-effective geohazard surveys.

TRANSITIONS

By documenting tectonically uplifted regions where reflectors are compressed, our work will help define coring locations where reflectors can be sampled and extrapolated to the basin at large. This will aid in the interpretation of long-term sequence stratigraphic packages, and provide a methodology whereby numerous offset short cores can provide data on otherwise inaccessible deep reflectors.

Work on the tectonic history of the Eel Basin directly impacts STRATAFORM by contributing to the knowledge base about long-term ($> 10^5$ yr) strata preservation. Gas analyes provide quantitative ground-truthing of features seen in high resolution sub-bottom profiling.

RELATED PROJECTS

Our work on the interaction of gas, seafloor morphology and reflectivity is being carried out in close concert with the high resolution sub-bottom profiling surveys (CHIRP sweep-frequency sonars) conducted by Neal Driscoll (WHOI). We are also working with Larry Mayer (U. New Hampshre) in assessing methods to associate the presence and amount of gas in near-surface sediments with the azimuthal variation of seafloor backscatter.

We are also working on reflector correlations between the multiple seismic and sub-bottom profiling data sets (Mike Field, USGS; Casey Moore, UCSC). We are collaborating with Craig Fulthorpe (U. Texas) and Greg Mountain (LDEO) in integrating our studies of the commercial MCS data with their high resolution MCS data.

PUBLICATIONS

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